EFFECT OF RAINFALL ON THE WATER LEVEL IN FUROSEN WELL OF BEPPU SPA

BY

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1. Introduction

The discharge of a hot spring in the old city of Beppu Spa has close relation with the rainfall. On analysis of the annual variations of well discharges, the relation between the discharge and the precipitation showed that 45% of the total discharges of all the hot springs there is fed by rainy water.[1]

It is a well-known correlation that a great amount of rainy water will be changed into hot water. The writer observed the fluctuations of the pressure head on the confined thermal water. The results analysed of the detail relation between the variation of the pressure head and the precipitation show that there is the linear relation between the increase of the pressure head and the precipitation, and that the influence of rainfall rapidly occurs on the pressure head.[2] With this fact, it is inferred that the confined thermal water should have close communication with the free ground water. Then, with the continuous records of the water level in a water table well in Furosen spring of Beppu Spa obtained by the water stage recorder since 1959, the effect of rainfall could be estimated.

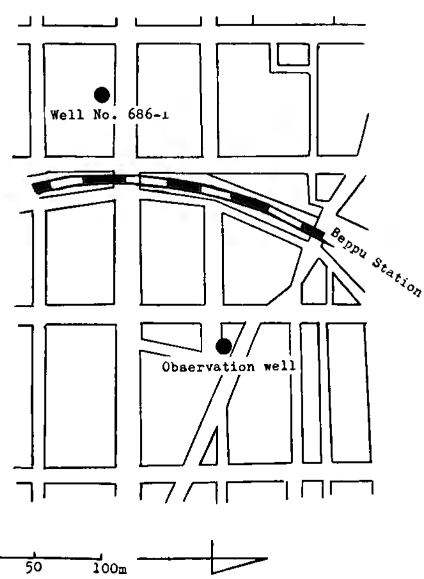

Fig. 1 Map showing location of observation well in Furosen of Beppu Spa.

2. The effect of rainfall on the free ground water

This observation well is dug as 4.5 m and locates as shown in Fig. 1. The fluctuations of water level caused by the variations of barometric pressure and also by the ocean tide can not be found. Therefore, the fluctuations of water level are caused chiefly by the rainfall. Fig. 2 shows the fluctuations of water level, the water temperature and the precipitation since Feb., 1959. The range of the annual variations is as small as about 20 cm. The highest levels occur

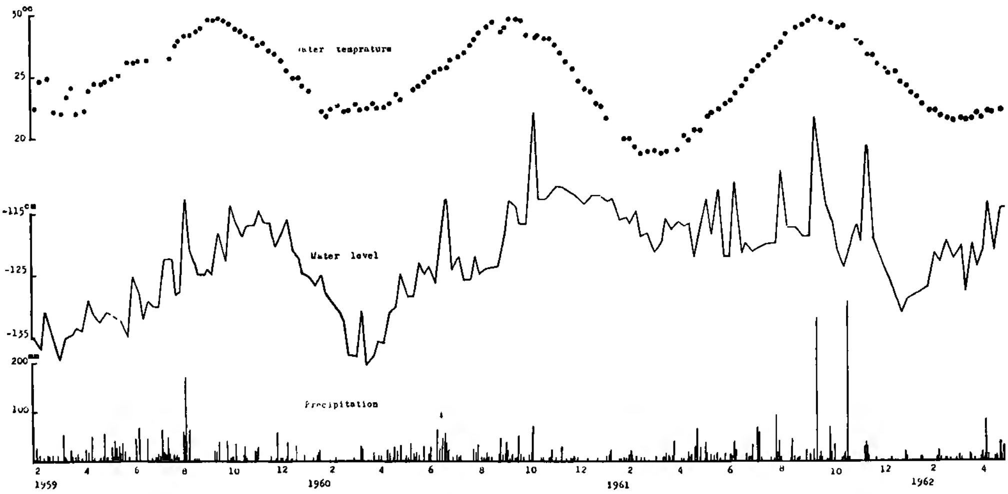

Fig. 2 Fluctuation of water level observed in the Furosen well of Beppu Spa.

about November, and the lowest about March. The water temperature fluctuates in the range of 30 and 18°C — the highest in September and the lowest in March. The highest ground temperature corresponding to this well depth is 21°C, which occurs in October. Most of water temperatures are so higher than this ground one that it may be inferred that the hot water leaked out from a deep aquifer should be mixed with the free ground water.

As seen at a glace of the fluctuations of water level in Fig. 2, the water level sharply fluctuates. These result from the influence of rainfall. Fig. 3 shows this behaviour in detail. Soon after the rain begins to fall, the water level rising starts and even if the rain left off, the water level keeps still rising and reaches the highest 1 or 2 hours later. Thereafter, in case of no rainfall, the water level gradually falls. This recession curves have two types shown as in Fig. 4.

The first type is the pattern that the water levels raised due to rainfall gradually fall and finally reach to the level before rainfall. From Fig. 4, these recession curves show the exponencial tendency, and the recession index of rainy effect is estimated as 0,61 (day^{-1}).

The second type: — The recession is slower than the first one, and the water level does not reach the original one before rainfall after the same time interval as the first type does. The influence of rainfall remains for a long time.

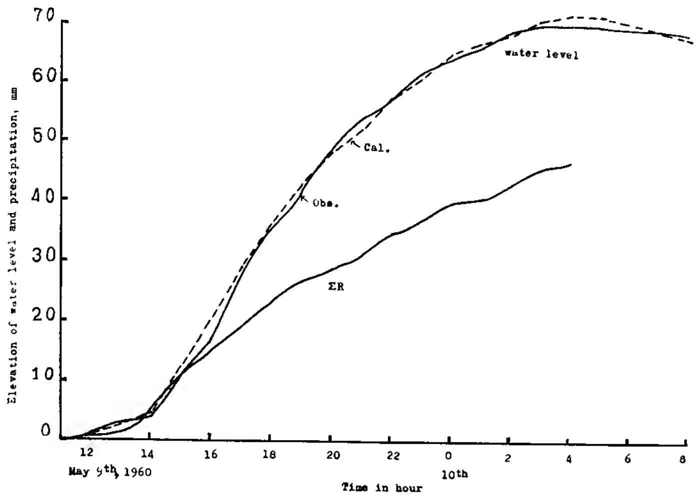

Fig. 3 Rising of water level caused by rainfall.

The characteristics of the both types have been searched to make the cause clear that occurs those two different types. The relation between the elevation of the water level caused by the string of rainfall and this precipitation is shown in Fig. 5. The effects of rainfall on the first type are smaller than on the second one, and there is the linear relation between them on the both types. This relation is expressed as follows.

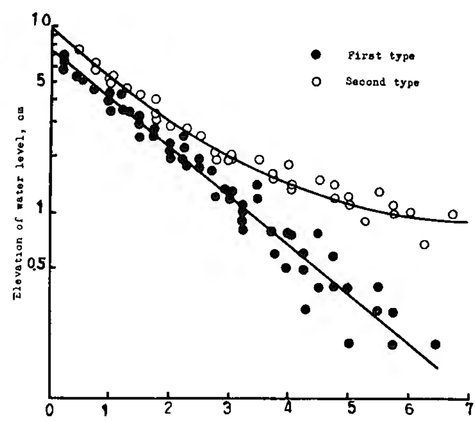

Fig. 4 Recession curves.

$$\Delta h=\beta\Delta R \qquad (1)$$

where Δh is the elevation of water level caused by rainfall, ΔR; β is the ratio of the elevation of water level to precipitation. So, it is called as the rainy efficiency, such as the tidal or the barometric one. From Fig. 5, β is estimated as 1.0 on the first type and 1.6 on the second.

With a view to study of the minor influence of rainfall, the hourly variation of the rainy efficiency was measured by the hourly elevation of water level and the hourly precipitation in consideration of the recession of water level. Those values are calculated by the following equations with application of the rest square,

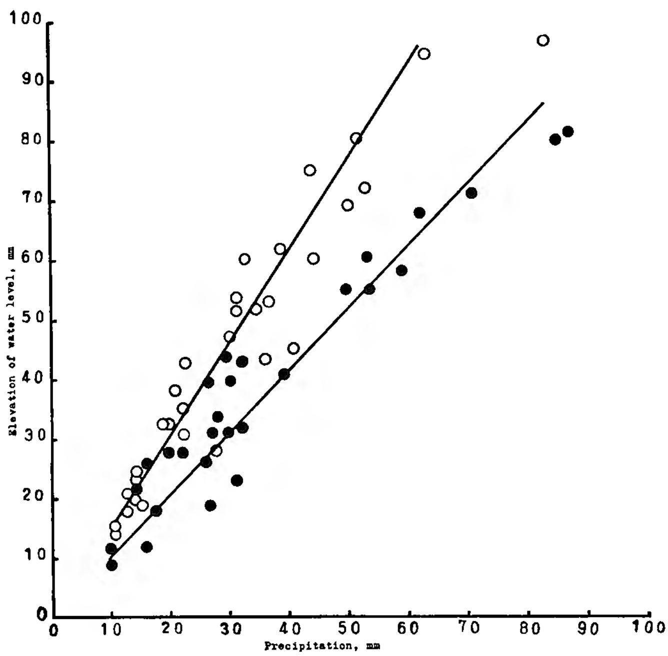

Fig. 5 Relation between the elevation of water level and precipitation.

$$\frac{\Delta h}{\Delta t}=-f(h,\ t)+\beta_0R_0+\beta_1R_1+\beta_2R_2+\cdots\cdots\cdots \tag{2}$$

The case of the first type.

$$\frac{\Delta h}{\Delta t}=-\alpha h+\beta_0R_0+\beta_1R_1+\beta_2R_2+\cdots\cdots\cdots \tag{3}$$

where β_0, β_1, β_2...... are the rainy efficiencies of the hourly precipitations, R_0, R_1, R_2,...... at the time t; R_0, R_1, R_2,...... are the hourly precipitations at hour t, t-1, t-2,......; α is the recession index of rainy effect. The above equations express that the hourly variation of water level equals to the sum of the hourly decrease of the level by recession and the elevation of the level caused by rainfall at that time t. The hourly rainy efficiencies about the several typical cases of each type

Table 1 Values of the hourly rainy efficiency

Rainy efficiency	β_0	β_1	β_2	β_3	Sum
Type 1	0.53	0.32	0.26	0.14	1.25
Type 2	0.88	0.61	0.30	0.16	1.95
Well No. 686-1	0.38	0.35	0.37	—	1.10

are calculated by the above equations, whose mean values are shown in Table 1.

Compared these values of the first type with the second one, the hourly rainy efficiencies on the second type are greater than those of the first in the early hour after rainfall and afterward, the both values become approximately equal. From those values of rainy efficiencies, it is inferred that the effect of rainfall will not be caused only by the load of the rainy water.

Compared the rainy efficiency of this well with the observed hot spring Well No. 686-1 (located about 200 m distant towards the southwest from this well, and its depth is 138 m), the former is greater than the latter, but the phase lag between them can not be found.

To search for the other characteristics showing the difference of the two types, the difference between heavy rain and drizzle, much and a little rain, or in the season, and of the variation of water temperature was carried out, but no different type can be found yet from the above mentioned. It is difficult at present to explain by what cause this phenomenon will be occurred. Perhaps this phenomenon appearing with these different types about rainy influence on the water level in this well may be caused by the local exceptional soil structure to infiltrate rainy water, or by mixing the cold ground water with the hot water leaked out from a deep aquifer.

3. Summary

The records of water level on the Furosen well of Beppu Spa show that the influence of rainfall rapidly occurs on the water level, which has two types with different rainy efficiency and the recession curve respectively.

The rainy efficiency on the first type is less than on the second one and the recession curve shows the exponencial tendency. The rainy efficiency on the second type is great, and the after effect of rainfall remains for a long time.

The hourly rainy efficiencies of the second type are greater than the first one in the early hour after the rainfall and the both of their values become approximately equal afterward.

Compared this rainy efficiencies with those of the confined thermal water, the former is greater than the latter, but the phase lag between them can not be found.

Acknowledgement

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References

1) T. Nomitsu, R. Ikeda & K. Seno, Rainfall and Juvenile Water as the Feeding Origins of the Hot Springs in Beppu, Mem, Coll. Science Kyoto Univ. Ser. A, Vol. 23, No. 3, pp. 41-74 (1940)
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